

Bounds on the Gluino Mass from a Global Parton Density Analysis ^a

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ABSTRACT

Parton distribution functions for protons are devised in which a light gluino is included along with standard model quark, antiquark, and gluon constituents. A global analysis of a large set of hadronic scattering data provides empirical constraints on the allowed range of the gluino mass as a function of the value of the strong coupling strength $\alpha_s(M_Z)$. We find that $m_{\tilde{g}} > 12$ GeV for the standard model world-average value $\alpha_s(M_Z) = 0.118$. Gluino masses as small as 10 GeV are admissible provided that $\alpha_s(M_Z) \geq 0.12$, about one standard deviation above the world-average value. Current hadron scattering data are insensitive to the presence of gluinos heavier than $\sim 100 - 150$ GeV.

1. Introduction

Once admitted, “light” supersymmetric (SUSY) states (mass $m < 100$ GeV), influence hadron scattering processes in several ways. They change the evolution of the strong coupling strength $\alpha_s(\mu)$ as the scale μ is varied. Second, they provide additional partonic degrees of freedom and share in the proton’s momentum along with their standard model (SM) counterparts, altering the coupled evolution equations that govern the functional change of the parton distributions as momentum is varied. Third, they contribute to hard-scattering processes as incident partons and/or as produced particles. For example, gluinos \tilde{g} materialize as hadron jets and may increase the rate for jet production at large values of transverse energy E_T . Within the context of a global analysis of hadron scattering data, these three influences allow potentially strong constraints to be placed on the existence and masses of SUSY particles. In this paper, I summarize the results of a new study of bounds on the gluino mass from a global parton density function (PDF) analysis [1].

In our study, we consider the effects of a light gluino only, and we do a series of fits to the full set of hadron scattering data used in the CTEQ6 PDF analysis [2] for various gluino masses $m_{\tilde{g}}$ and values of $\alpha_s(M_Z)$. All SM contributions are evaluated in perturbative QCD at next-to-leading order (NLO). The \tilde{g} contributions to the parton density evolution and jet production cross section are evaluated at Born level (sufficient because $\tilde{g}(x) \ll q(x), g(x)$). Data on hadron jet production from the Fermilab Tevatron, $p\bar{p} \rightarrow \text{jet} + X$ at large E_T are included in the fit. Quantitative bounds on $m_{\tilde{g}}$ are obtained

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from a PDF error analysis similar to that of CTEQ6.

1.1. Role of $\alpha_s(M_Z)$

Our conclusions on the allowed values of $m_{\tilde{g}}$ depend on what is assumed for $\alpha_s(M_Z)$, the value at which the evolution of $\alpha_s(\mu)$ is pinned, but we must and do fit data at all μ . In our PDF analysis, we perform a series of fits to the hadron scattering data in which $\alpha_s(M_Z)$ is varied over the broad range $0.110 \leq \alpha_s(M_Z) \leq 0.150$. We then impose the direct Z -pole two standard deviation (2σ) bounds on $\alpha_s(M_Z)$ to establish bounds on $m_{\tilde{g}}$.

A combined analysis of all Z -pole data within the context of the SM provides $\alpha_s(M_Z) = 0.1187 \pm 0.0027$ [3]. The SM world-average obtained from a variety of determinations at different scales μ yields $\alpha_s(M_Z) = 0.1183 \pm 0.0027$ [4]. Although we use these values to obtain our bounds on $m_{\tilde{g}}$, we are mindful that SUSY-QCD contributions can affect the extraction of $\alpha_s(\mu)$. A recent estimate [5] finds $\alpha_s(M_Z) = 0.118 - 0.126 \pm 0.005$, where the variation in the central value arises from uncertainty in the size of SUSY-QCD corrections to the Z width from, e.g., $Z \rightarrow b\tilde{b}^*\tilde{g}/\tilde{b}\tilde{b}\tilde{g}$; \tilde{b} denotes a bottom squark. As remarked later, a larger value of $\alpha_s(M_Z)$ permits smaller values of $m_{\tilde{g}}$.

1.2. Parton distribution function (PDF) analysis

The PDF's $f(x, Q)$ are parametrized at a starting reference scale Q_0 and evolved to all $Q > Q_0$. The gluino distribution is generated radiatively from gluon splitting for $Q > m_{\tilde{g}}$. The coupled evolution equations in the presence of a light gluino may be found in Ref. [1]. Normalized cross sections are calculated based on the parton distributions. Agreement with experiment is measured by χ^2 . The PDF shape parameters at $Q = Q_0$ are varied to minimize χ^2 . The gluino parton density remains very small with respect to the SM quark and gluon densities for all accessible values of Q . The gluinos remove momentum primarily from the gluon density, for values of $x > 0.05$. Since hadron jet data at large values of E_T are known to probe the gluon density at large x , inclusion of these data in the fit plays a strong role in constraining $m_{\tilde{g}}$.

1.3. SUSY hard-scattering contributions

Once SUSY particles are admitted as degrees of freedom, we must consider their impact on all hard scattering processes. For jet production in $\bar{p} + p \rightarrow \text{jet} + X$, we include $\mathcal{O}(\alpha_s^2)$ subprocesses with gluinos produced in the final state and either one or no gluinos in the initial state: $q + \bar{q} \rightarrow \tilde{g} + \tilde{g}$, $g + g \rightarrow \tilde{g} + \tilde{g}$, $g + \tilde{g} \rightarrow g + \tilde{g}$, and $q + \tilde{g} \rightarrow q + \tilde{g}$. Contributions to the cross section from these processes are added to the $\mathcal{O}(\alpha_s^2)$ SM contributions, and they offset partially the loss of jet rate from the smaller gluon PDF. In deep-inelastic scattering and in massive-lepton-pair production, the SM processes contribute at $\mathcal{O}(\alpha_s^0)$, but the SUSY processes enter at $\mathcal{O}(\alpha_s^1)$. We can neglect $\mathcal{O}(\alpha_s^1)$ SUSY subprocesses such

as $\gamma^* + g \rightarrow \tilde{q} + \tilde{g}$, where \tilde{q} denotes a squark, and $\mathcal{O}(\alpha_s^2)$ subprocesses $\gamma^* + q \rightarrow q + \tilde{g} + \tilde{g}$.

2. Results

Our principal results are presented in the form of a contour plot. We show the difference $\Delta\chi^2$ between the value of χ^2 obtained in our fit and that of a purely SM fit equivalent to the CTEQ6M fit. The CTEQ6 tolerance criterion for an acceptable fit is $\Delta\chi^2 < 100$; the isoline corresponding to $\Delta\chi^2 = 100$ is shown in Fig. 1 by the solid line. The acceptable fits lie inside a valley that extends from large gluino masses and $\alpha_s(M_Z) = 0.118$ down to $m_{\tilde{g}} \approx 0.8$ GeV and right to $\alpha_s(M_Z) = 0.145$. An even narrower area corresponds to fits with χ^2 close to those in the CTEQ6M fit. We note that χ^2 is better than in the CTEQ6M fit in a small area in which $m_{\tilde{g}} < 20$ GeV and $\alpha_s(M_Z) > 0.125$, with the minimum $\Delta\chi^2 \approx -25$ at $m_{\tilde{g}} = 8$ GeV and $\alpha_s(M_Z) = 0.130$. While perhaps intriguing, this negative excursion in $\Delta\chi^2$ is smaller than the tolerance $\Delta\chi^2 = 100$ and cannot be interpreted as evidence for a light gluino. We determine that $m_{\tilde{g}} > 12$ GeV at $\alpha_s(M_Z) = 0.118$. The lower limit increases as $\alpha_s(M_Z)$ rises; for example, with $\alpha_s(M_Z) = 0.122$, $\sim 1 \sigma$ above the SM world average, $m_{\tilde{g}} > 5$ GeV.

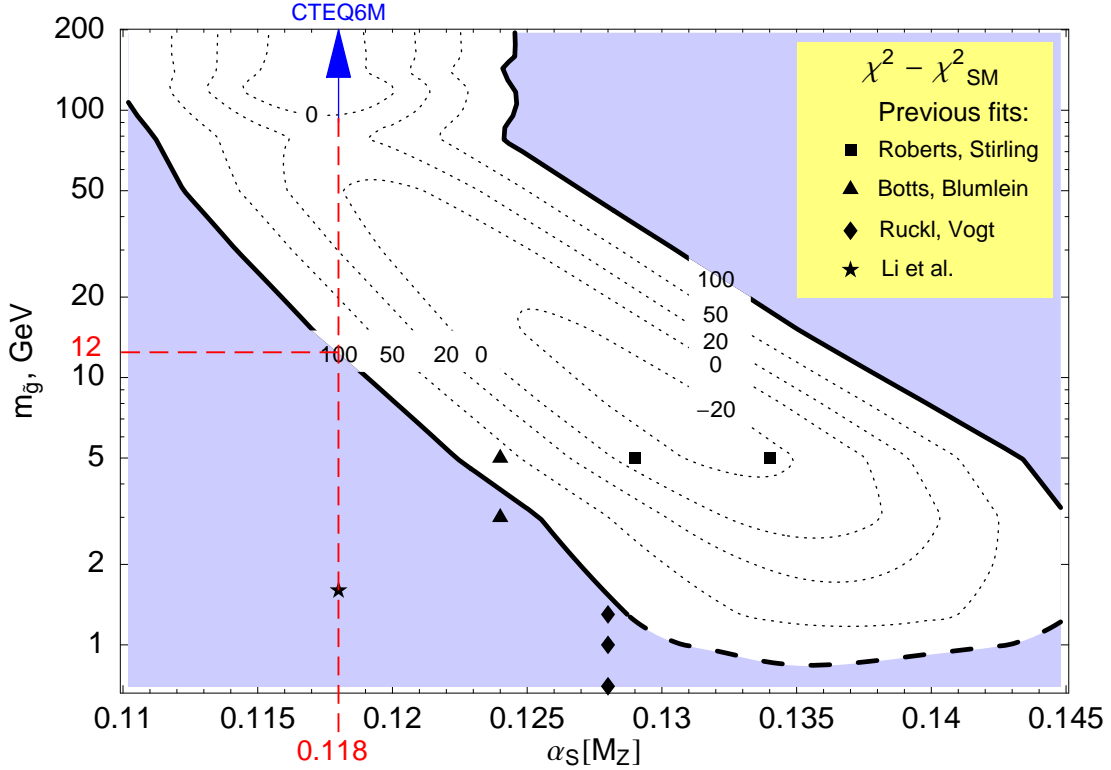


Figure 1: Contour plot of $\Delta\chi^2 = \chi^2[\alpha_s(M_Z), m_{\tilde{g}}] - \chi^2_{\text{CTEQ6M}}$ obtained from our fits to hadronic scattering data for various $m_{\tilde{g}}$ and $\alpha_s(M_Z)$. The value of $\alpha_s(M_Z)$ serves as the abscissa, with the gluino mass along the ordinate. The vertical dashed line marks the SM value $\alpha_s(M_Z) = 0.118$.

3. Comparison with other bounds on $m_{\tilde{g}}$

Our global analysis is based on theoretically clean one-scale observables only. We make no assumptions about the stability of the superpartners. Our bound $m_{\tilde{g}} > 12$ GeV is stronger than the bound $m_{\tilde{g}} > 6.3$ GeV at $\alpha_s(M_Z) = 0.118$ found in a study of the Z boson width measurements [6]. Negative searches for *stable* hadronizing gluinos provide bounds of $m_{\tilde{g}} > 18$ GeV [7] and $m_{\tilde{g}} > 26.9$ GeV [8], but these bounds do not apply if the gluino decays through an R -parity violating mechanism [9]. Based on a study of jet shape variables, the DELPHI collaboration derives a limit $m_{\tilde{g}} > 30\text{--}40$ GeV [10]. However, their analysis deals with multi-scale observables, and the treatment of theoretical uncertainties may be too optimistic.

4. Conclusions

In our work, we obtain model-independent bounds on the existence and mass of color-octet fermions (gluinos) based on a fit to the complete CTEQ6 set of inclusive hadron scattering data (1811 points). The data are characterized by high precision and cover a broad range in x and Q^2 . We include SUSY contributions to the Tevatron jet production cross sections and use the full CTEQ error analysis to obtain our bounds. We determine that $m_{\tilde{g}} > 12$ GeV for $\alpha_s(M_Z) = 0.118$, with smaller values of $m_{\tilde{g}}$ allowed for larger $\alpha_s(M_Z)$. The possibility [11] remains open for $m_{\tilde{g}} = 10\text{--}20$ GeV if $\alpha_s(M_Z) > 0.119$. For $\alpha_s(M_Z) > 0.124$, $m_{\tilde{g}}$ is also bounded from above. The PDF analysis of current hadron scattering data is not sensitive to gluinos with mass $m_{\tilde{g}}$ above the weak-scale, but inclusion of a gluino with $m_{\tilde{g}} \sim 100$ GeV slightly improves the description of jet data at high E_T [1]. Our study is complementary to those in which bounds $m_{\tilde{g}}$ are derived from LEP data, and it demonstrates the potential for PDF analysis to independently constrain new physics in the next few years once high precision data extend to larger values of Q .

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